Deep Learning-Based X-ray Shoulder Balance Assessment: Development, Validation, and Application in Adolescent Idiopathic Scoliosis

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INTRODUCTION: Adolescent Idiopathic Scoliosis (AIS) is a three-dimensional spinal deformity affecting spinal morphology. Shoulder imbalance not only impacts the patient's appearance and satisfaction but also leads to functional problems due to trunk imbalance. Accurate assessment of shoulder balance parameters is crucial for decision-making and treatment outcome improvement. Nonetheless, there existed significant variability in terms of the consistency of shoulder assessment, coupled with a complex procedure for physicians. In recent years, the rapid development of deep learning technology has offered a new approach to address this issue. The aim of this study is to develop a deep learning neural network-based method for automated measurement of shoulder balance parameters in AIS patients and to validate its clinical applicability.

METHODS: This study has been reviewed and approved by the ethics board of Shanghai Tongji Hospital. 5,000 AIS patient coronal whole-body X-rays from Shanghai Tongji Hospital were included as the dataset, stored in the DICOM 3.0 protocol format. Annotation of the dataset was performed by two attending physicians and reviewed by a chief physician on the open-source *Labeling Anything* including bilateral clavicles and coracoids. We developed a deep learning neural network architecture based on VGG to facilitate the segmentation and feature extraction of bilateral clavicles and coracoids from raw X-ray images. Contours are calculated based on segmentation masks, and essential key points are extracted for parameter calculation, encompassing the Clavicle Angle (CA), Radiological Shoulder Height (RSH), Coracoid Height Difference (CHD), and Clavicle Tilt Angle Difference (CTAD). The parameters are measured on external data of 100 AIS X-rays by three senior spine surgeons using a self-developed platform equipped with appropriate parameter measurement tools. A comprehensive comparison of measurement errors and accuracy is then conducted against the system's output results.

RESULTS SECTION: Our deep learning neural network model demonstrated high accuracy and stability in shoulder balance parameter measurements. Compared to traditional methods, our approach achieved more accurate clavicle and coracoid segmentation, with an Intersection-Over-Union (IoU) of 0.96. The Mean Absolute Error (MAE) for all four parameters was ≤1.7°, enabling precise measurement and assessment. Additionally, correlations were found between CA, RSH, CHD and CTAD.

DISCUSSION: The application of deep learning in shoulder balance assessment presents an innovative and efficient approach. The Resnet-based architecture enabled robust segmentation and accurate parameter calculation. A limitation of our study is the lack of comprehensive testing of the model's generalization ability. It may not accurately assess shoulder balance in cases of severe deformities or images with poor quality.

SIGNIFICANCE/CLINICAL RELEVANCE: The neural network contributes to faster assessments and reduces the reliance on individual expertise. This is especially valuable in clinical settings where healthcare professionals often juggle multiple cases simultaneously. With our algorithm, the assessment process can be standardized, ensuring consistent and accurate measurements across different physicians.
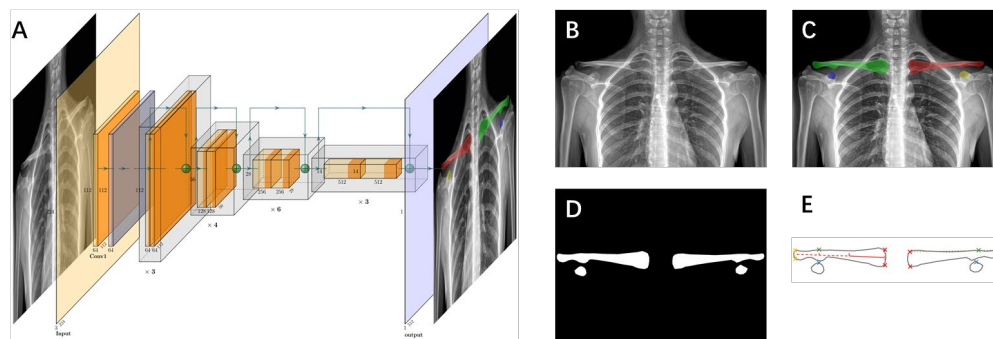

Fig 1. A) Schematic of the VGG architecture neural network of the clavicles and coracoids segment; B) Original X-ray; C) Segment annotations of the clavicles and coracoids; D) Predicted masks of the clavicles and coracoids; E) Key points of shoulder balance including CA, RSH, CHD and CTAD.
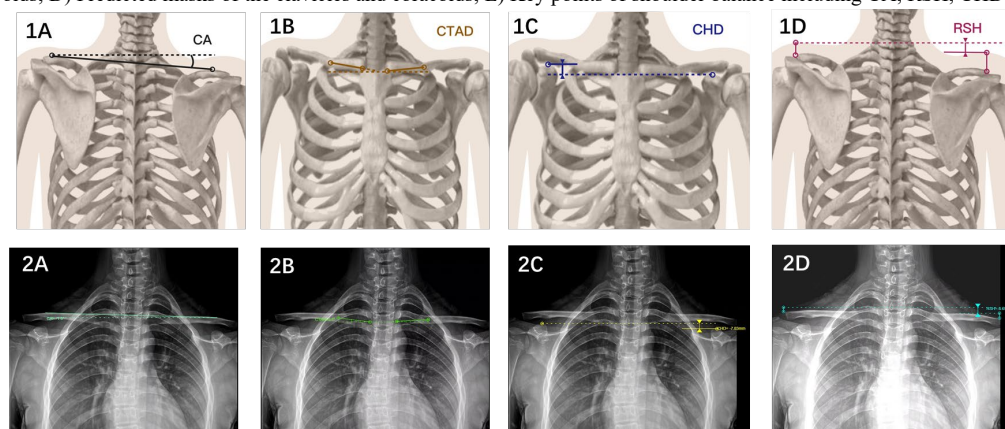

Fig 2. 1) Schematic of shoulder balance parameters; 2) Measurement tools of shoulder balance parameters; A: Clavicular Angle (CA); B: Clavicle Tilt Angle Difference (CTAD); C: Coracoid Height Difference (CHD); D: Radiological Shoulder Height (RSH).